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TECHNICAL REPORT 3

BEARING-RIDER CONTROL WITH CENTROID TRACKING

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13. ABSTRACT

A study is made of the motion of the centroid bearing line and the effects of this motion when bearing-rider control is exercised. Acquisition probabilities are computed by suitable modifications to a previously developed simulation model, and compared with the corresponding probabilities obtained with bearing-rider control when a torpedo maneuver is used to unmask the target, and with the corresponding probabilities obtained with corrected-intercept control when centroid tracking is used. Some plots of the tracks of the target submarine, tracking submarine, torpedo, and guide point are shown to illustrate the effects of the control modes and noise levels.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Bearing-Rider						
Corrected-Intercept						
Torpedo MK 48						
Centroid-Tracking						

BEARING-RIDER CONTROL WITH CENTROID TRACKING*

Introduction

Centroid tracking, in which the sonar operator tracks a composite
signal at a bearing that is a weighted average of the torpedo and
target bearings, is described in reference (a). The motion of
the composite bearing line depends on the control mode and the
corresponding procedure for computing changes in the torpedo
course angle. The motion of the composite bearing line and the
effect on acquisition probability were studied in reference (a)
for the corrected-intercept control mode.

The analysis is extended to bearing-rider control in this report.
Acquisition probabilities are computed and compared with those
obtained in reference (a) with corrected-intercept control, and
with those obtained in reference (b) with dog-leg unmasking.

Summary and Conclusions

Bearing-rider control produces good results with centroid track-
ing when the target is louder than the torpedo at the source.
Acquisition probabilities are higher than those obtained by
using dog-leg unmasking in the control mode called constrained
bearing-rider in reference (b), for almost all runs, cases, and
conditions tested. Acquisition probabilities with bearing-rider
control are comparable with those obtained in reference (a) with
corrected-intercept control, provided the target is louder than
the torpedo at the source. If the torpedo is louder than the
target at the source, corrected-intercept control (with our new
TMA) is definitely superior to bearing-rider control.

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The results obtained with bearing-rider control when the torpedo noise is dominant depend on the bearing line to the torpedo when torpedo capture of the tracking beam occurs at the start of post-launch tracking, the position of the target relative to this bearing line, and the subsequent motion of the target normal to the bearing line. Bearing-rider control, under these conditions, puts the torpedo on a course that is almost directly away from the tracking submarine. The outcome may be better or worse than the outcome obtained with no post-launch control, depending on the circumstances that exist when post-launch control is exercised.

Effects of Centroid Tracking on Bearing-Rider Control

The apparent bearing of the composite signal is

$$B^* = (B + \rho B_T) \, / \, (1 + \rho) \tag{1}$$

where

$$\rho = (R/R_T)^2 \, e^{-0.23(\Delta G + \Delta H)} \tag{2}$$

(R, B) are the range and bearing of the target,

(R_T, B_T) are the range and bearing of the torpedo,

ΔH = signal strength difference at the source (target minus torpedo)

ΔG = corresponding difference in directional sensitivities

In the bearing-rider control the bearing of the guide point is computed by dead-reckoning the position of the torpedo, and the difference between the apparent bearing B^* of the target and the computed bearing $\hat{B}_g$ of the guide point is used in the control operation. Hence, we need an estimate of $B^* - \hat{B}_g$ to determine the corrections that bearing-rider control will apply.

Since the guide point leads the torpedo by the distance d_g and the torpedo is on course Θ, the bearing B_g of the guide point is

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$$B_g = B_T + \arctan\left(\frac{d_g \sin(\theta - B_T)}{R_T + d_g \cos(\theta - B_T)}\right) \tag{3}$$

If $\left|\theta - B_T\right|$ is small, B_g can be approximated by

$$B_g \doteq B_T + (d_g/R_g)(\theta - B_T) \tag{4}$$

where R_g is the range to the guide point. When B_T is estimated by dead-reckoning the corresponding estimate of B_g is approximately

$$\hat{B}_g = \hat{B}_T + (d_g/R_g)(\theta - \hat{B}_T) \tag{5}$$

From equations (1), (4), and (5) the bearing difference that is used in bearing-rider control is

$$B^* - \hat{B}_g = (B - B_g)/(1+\rho) + \rho d_g (B_T - \theta)/R_g(1+\rho) + (B_T - \hat{B}_T)(1 - d_g/R_g) \tag{6}$$

The first term on the right-hand side of (6) is the component that we would like to make zero. The second term occurs because we are tracking the apparent target bearing instead of the true target bearing. The third term is the error that occurs from the error in estimating the bearing of the torpedo; presumably it usually is within the control tolerance limits that must be exceeded to trigger an order for a change in the torpedo course angle θ.

If ρ is small, the control orders that are given to make $\left|B^* - \hat{B}_g\right|$ small also will make $\left|B - B_g\right|$ small, as desired. If ρ is large, the second term in (6) usually is the dominant term. Hence, attempts to make $\left|B^* - \hat{B}_g\right|$ small will make $\left|B_T - \theta\right|$ small, which is not the desired objective. As θ is altered to make $\left|B_T - \theta\right|$ small, the torpedo is brought to a course that is almost directly away from the controller, which may or may not be a good course for acquisition. The exercise of bearing-rider control may produce worse results than no control, in this case, particularly when $(B - B_g)$ and $(B_T - \theta)$ have opposite signs.

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The dominance of the second term in (6) when ρ is large can be avoided by putting $d_g = 0$, that is, by controlling the torpedo instead of the guide point. However, the first term in (6) then is too small to trigger a control order, even when $\left| B - B_g \right|$ is large. If we decrease the tolerance interval, in an attempt to allow control to be exercised by the term $(B-B_g)/(1+\rho)$, we run the risk of controlling by the error term $(B_T - \hat{B}_T)(1 - d_g/R_g)$. Hence, there appears to be no effective control that can be exercised in the bearing-rider mode when the torpedo is louder than the target. This theoretical conclusion was verified by the results obtained from the simulation model.

Simulation Model

The simulation model for the bearing-rider mode that is described in reference (b) was revised to remove the dog-leg unmasking and to insert the simulation of centroid tracking. The required changes in the computation of the acquisition probability also were made. The revised computational procedure is outlined in the Appendix. It was programmed and used to compute acquisition probabilities for the same runs used in references (a) and (b).

Comparison Conditions

The five run types and five maneuver times described in reference (b) were used again. The parameter values listed in Table 3.1 of reference (b) and in Table 1 of reference (a) were used where applicable. Some parameters were eliminated when the dog leg was eliminated; and some parameters, such as the damping parameters, that were introduced for corrected-intercept control are not required in bearing-rider control.

Results

Acquisition probabilities obtained from the computations are listed in Tables 1 and 2. Values for all runs and cases with

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ΔH=5 db are listed in Table 1 for bearing-rider controls, to-
gether with the corresponding values for no control, bearing-
rider control with dog-leg unmasking, and corrected-intercept
control with centroid tracking. The values listed for corrected-
intercept control with centroid tracking are those obtained with
40 percent proportional navigation as the damping mode.

Two sets of probabilities are listed for no control. In dog-leg
unmasking it is assumed that the dog leg is programmed, whether
or not control is exercised, and that after completion of the
dog leg the torpedo is turned to the interception course based
on the initial TMA. In centroid tracking it is assumed that the
torpedo continues on the initial course when no control is exer-
cised. Hence, the final torpedo courses for the two cases of
no control can be quite different, which accounts for the large
differences in the acquisition probabilities for some cases.

For ΔH=5 db the use of centroid tracking yields consistently
better results than those obtained with dog-leg unmasking. For
runs 1 and 3, which are turns of 60 and 120 degrees away from
the tracking submarine, the gains obtained from the use of
centroid tracking are large.

Bearing-rider control and corrected-intercept control are
roughly comparable control modes in the use of centroid tracking
when ΔH=5 db, neither one being consistently superior to the
other. However, as ΔH decreases, corrected-intercept control
retains its effectiveness while bearing-rider control decreases
in effectiveness. Results are shown for run 3 in Table 2.
Corrected-intercept control is superior to bearing-rider control
when ΔH=0 db and is greatly superior when ΔH= -5 db, for all
cases except case 2. In case 2, the initial course of the tor-
pedo puts the target and torpedo on nearly the same bearing from
the tracking submarine at the start of post-launch tracking;
hence, the apparent bearing nearly coincides with the true

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TABLE 1. ACQUISITION PROBABILITIES FOR ΔH=5 db.

Run	Case	Dog Leg		Centroid Tracking		
		No Control	B-R	No Control	B-R	C-I
1	1	.34	.16	.39	.52	.45
	2	.49	.18	.41	.55	.52
	3	.47	.21	.35	.56	.57
	4	.50	.20	.38	.60	.61
	5	.54	.21	.41	.63	.64
2	1	.77	.64	.73	.81	.82
	2	.75	.63	.69	.79	.81
	3	.69	.60	.57	.76	.79
	4	.67	.52	.52	.74	.77
	5	.65	.44	.50	.72	.75
3	1	.32	.19	.46	.47	.41
	2	.34	.07	.31	.48	.45
	3	.33	.22	.31	.54	.56
	4	.42	.21	.36	.59	.62
	5	.51	.22	.41	.63	.66
4	1	.80	.54	.80	.79	.86
	2	.78	.72	.83	.85	.86
	3	.58	.73	.50	.75	.73
	4	.63	.48	.50	.74	.72
	5	.65	.39	.50	.72	.73
5	1	.59	.44	.43	.67	.67
	2	.58	.33	.52	.69	.68
	3	.59	.28	.45	.68	.68
	4	.59	.27	.45	.68	.69
	5	.59	.27	.45	.68	.69

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TABLE 2. ACQUISITION PROBABILITIES FOR RUN 3
(120 DEGREES TURN AWAY)

Case	ΔH = 5 db		ΔH = 0 db		ΔH = -5 db	
	C-I	B-R	C-I	B-R	C-I	B-R
1	.41	.47	.50	.34	.50	.17
2	.45	.48	.49	.48	.48	.48
3	.56	.54	.55	.37	.49	.16
4	.62	.59	.61	.46	.60	.27
5	.66	.63	.64	.55	.65	.41

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bearing of the target and bearing-rider control yields nearly the same track for all three values of ΔH.

Attempts to control the torpedo in the bearing-rider mode may lead to a lower acquisition probability than that obtained with no control, when ΔH is negative. In these cases, the torpedo captures the tracking beam and the use of bearing-rider control makes the gyro course angle Θ nearly equal to the torpedo bearing B_T, as explained above in the discussion of equation (6). This change in Θ may produce a worse course for interception than the initial course, as in cases 1, 3, and 4 of run 3; it may produce a better course for interception, as in case 2 of run 3; or it may produce no change, as in case 5 of run 3.

The adverse effects of control that sometimes are obtained with negative values of ΔH can be avoided by controlling the torpedo, rather than the guide point. However, when the computations were repeated with $d_g = 0$, no control orders were generated and the acquisition probabilities were equal to those obtained with no control. There appears to be no modification of the bearing-rider control procedure that will produce results that are consistently better than those obtained with no control when ΔH is negative. Hence, corrected-intercept control is definitely superior to bearing-rider control under these conditions.

The effect that the value of ΔH can have is shown in Figure 1, which is a CalComp plot of the target, torpedo, guide point, and own submarine for run 3, case 3. The gaps and the apparent sudden changes in course are the result of the times and time intervals chosen for plotting, not a limitation in the computed results. The positions at the start of tracking and at launch are the first two plotted points; thereafter points are plotted at intervals of 30 seconds, whereas the control orders and conditional acquisition probabilities (conditional on wire breakage) were computed at intervals of 2 seconds.

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From Figure 1 it is seen that bearing-rider control is very effective when $\Delta H=5$ db and is very ineffective when $\Delta H= -5$ db for case 3 of run 3. When control is exercised for $\Delta H= -5$ db the torpedo is turned to a worse course for interception than the original course.

The corresponding plot is shown for the corrected-intercept control mode in Figure 2. Good results also are obtained with this control mode when $\Delta H=5$ db, although the track of the torpedo and guide point are not as smooth and direct as those obtained in bearing-rider control. The acquisition probabilities for the two control modes are approximately equal, as shown in Table 1.

The rapid oscillation of the guide point, which is a magnification of a small oscillation in the torpedo course angle, is produced by rapid changes in the computed lead angle for interception that occur when the estimated position of the guide point approaches the estimated position of the target. Without the damping constraints, described in reference (a), the torpedo could be turned to a radically different course or to a circular or figure-8 track around the estimated target position. This undesirable motion also could be avoided by termination of control, which had been used in the earlier models. However, the acquisition probabilities obtained with damping are higher than those obtained with termination of control. The rapid oscillations could be removed by a simple modification of the control procedures, which may or may not produce an increase in acquisition probabilities. This modification will be tested at a later date.

It is evident from Figures 1 and 2 that corrected-intercept control improves the torpedo track somewhat when $\Delta H= -5$ db. A comparison of the tracks for the two control modes is made in Figure 3. Although the track obtained with the corrected-intercept mode is definitely closer to the target track than that obtained with the bearing-rider mode, it lags by an appreciable amount. However, the lag is not much greater for $\Delta H= -10$ db,

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for which the acquisition probability is 0.45, compared with
0.49 for $\Delta H = -5$ db.

No modification of the control procedures in the corrected-
intercept control mode have been conceived to remove the inherent
lag noted above. And perhaps it is too much to hope for. The
fact that any effective control from centroid tracking can be
exercised when ΔH is negative had not been anticipated.

References:

(a) ADL Technical Report ADL-72580-1, "Corrected-Intercept
Control of Torpedo MK 48 with Centroid Tracking",
September 1970, Unclassified

(b) ADL Report NUWRES #12, "Control Modes and Acquisition
Probabilities for Torpedo MK 48 (U)", Contract No.
N00140-68-C-0278, January 1970, Final Report Confidential,
Technical Appendices (bound separately) Unclassified.

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APPENDIX

COMPUTATIONAL PROCEDURE FOR THE B-R MODE WITH CENTROID TRACKING

The computational procedure for the bearing-rider mode when a dog leg is used to unmask is given in Appendix E of reference (b). The procedure for the computation of the centroid bearing B^* is listed in the Appendix of reference (a). The desired computational procedure is obtained by removing the dog-leg unmasking computations and inserting the computations to obtain the apparent bearing B^* that replaces the target bearing.

A careful examination of the procedures in references (a) and (b) was made to check the equations needed to make the changes outlined above. No new equations are needed. The required changes in the program were made, and the new program was checked against a test case. Of course, the program did not run. The difficulties were traced to indexing mismatches in the control loops, an error in the arbitrary equation used to compute the upper limit of an index range, and several spooks. One spook was the motion of the torpedo course angle away from the target when bearing-rider control is exercised with ΔH negative, before the reason for this motion was revealed by graphical analysis and confirmed by the analysis of equation (6).

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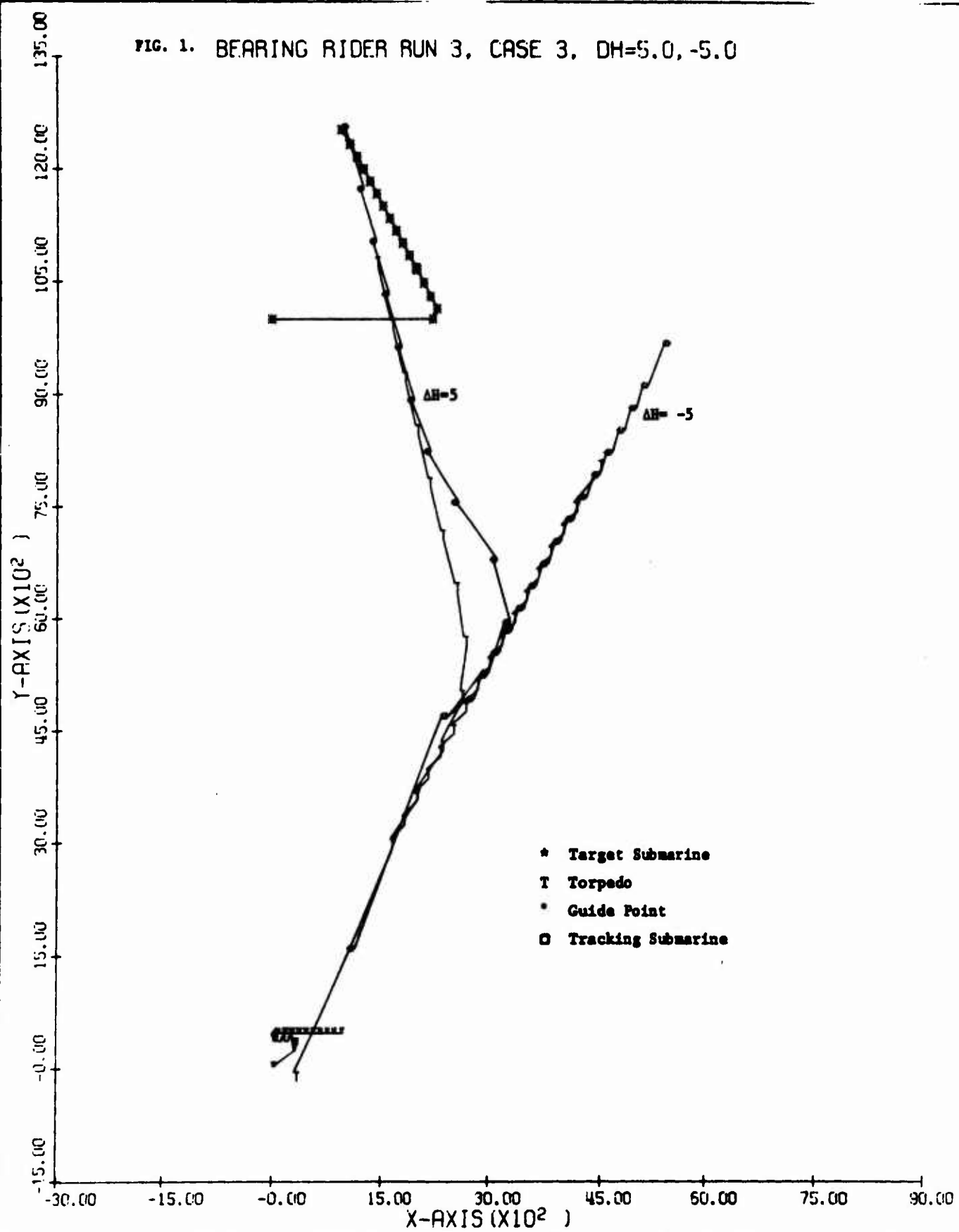
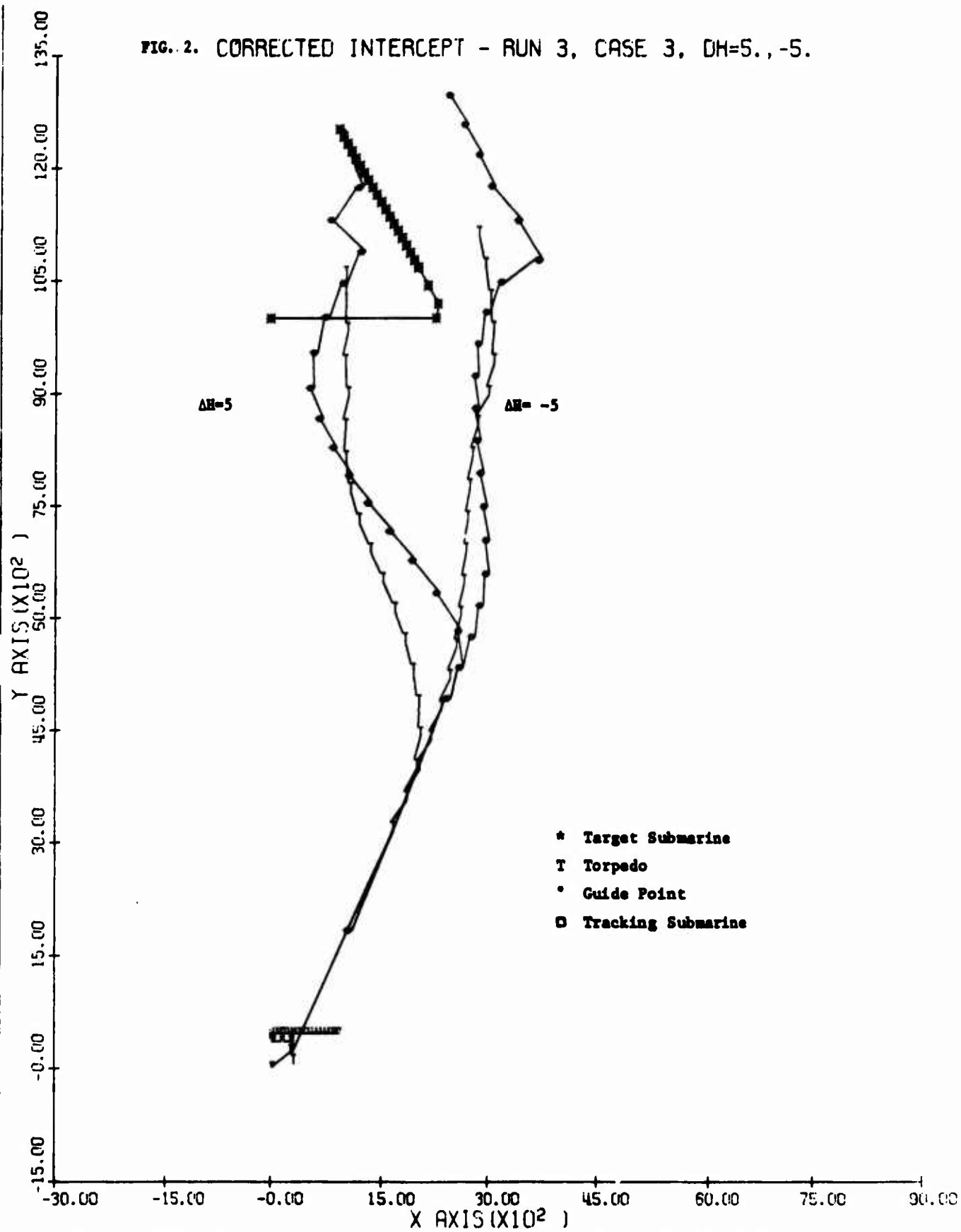FIG. 1. BEARING RIDER RUN 3, CASE 3, DH=5.0, -5.0

FIG. 2. CORRECTED INTERCEPT - RUN 3, CASE 3, DH=5.,-5.

FIG. 3. BEARING RIDER AND CORRECTED INTERCEPT, DH=-5.0

C-I

B-R

* Target Submarine
T Torpedo
• Guide Point
□ Tracking Submarine